NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

January 1946 as
Advance Confidential Report L5F28

WIND-TUNNEL INVESTIGATION OF AN NACA 66-SERIES 16-PERCENT-THICK LOW-DRAG TAPERED WING WITH FOWLER AND SPLIT FLAPS

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SUMMARY

Tests were made to determine the aerodynamic characteristics of an NACA 66-series 16-percent-thick low-drag tapered wing with Fowler and split flaps. The wing had a straight trailing edge and a constant-chord center section. The lift, drag, pitching-moment, and stalling characteristics of the wing are presented.

The maximum lift coefficients obtained at a Reynolds number of 3.5×10^6 were 2.49 and 3.27 with partial-span and full-span Fowler flaps, respectively, and 2.07 and 2.43 with partial-span and full-span split flaps. The values of maximum lift coefficient for the low-drag wing with split flaps were somewhat lower than the values obtained for comparable wings with conventional airfoil sections. Trimming the large pitching moments due to flaps appreciably reduced the maximum lift available, particularly for the wing with Fowler flaps. For all configurations investigated the wing stalled suddenly, and in most cases completely, for a very small increase in angle of attack beyond maximum lift.

The data given supersede all previous data on the subject wing.

INTRODUCTION

An investigation was undertaken several years ago in the Langley 19-foot pressure tunnel to obtain information regarding the aerodynamic characteristics in three-dimensional flow of representative wings with NACA low-drag airfoils and various high-lift devices. Preliminary tests were made of a low-drag tapered wing of 15-foot span with a straight trailing edge and several arrangements of trailing-edge flaps. A great deal of difficulty was encountered in obtaining valid measurements of the characteristics primarily because of errors in corrections for model-support tare and interference and because of inaccuracies of the tunnel balances. Some of the data for the wing with split flaps were published in reference 1. Later tests of the same wing (15-foot span) and a smaller but geometrically similar wing (12-foot span) indicated that these data were in error for the aforementioned reasons.

Recently the investigation was continued with tests of the small (12-foot-span) wing to obtain data under more favorable test conditions, namely, improved tunnel balances and testing techniques. The wing was tested with partial- and full-span arrangements of 0.30-chord Fowler flaps and 0.20-chord split flaps.

Lift, drag, pitching-moment, and stalling characteristics are given in the present report. The results supersede the data of reference 1.

COEFFICIENTS AND SYMBOLS

The data presented in this report are given as standard nondimensional coefficients based on the mean chord and area of the wing with flaps retracted.

C_L lift coefficient $\left(\frac{L}{qS}\right)$

$C_{L_{max}}$ maximum lift coefficient

$\Delta C_{L_{max}}$ increment of maximum lift coefficient measured from maximum lift coefficient of wing with flaps retracted

C_D drag coefficient $\left(\frac{D}{qS}\right)$

C_m pitching-moment coefficient $\left(\frac{M}{qS\bar{c}}\right)$

where

L lift

D drag

M pitching moment about quarter-chord point of plain-wing root section

S wing area

$\bar{c}$ mean chord (S/b)

q free-stream dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$

and

ρ mass density of air

V free-stream velocity

b wing span

c wing-section chord

δ_f flap deflection

α angle of attack measured from chord line of root section

R Reynolds number $(\rho V\bar{c}/\mu)$

M Mach number (V/a)

μ coefficient of viscosity

a speed of sound

APPARATUS AND TESTS

Models

The general arrangement of the wing equipped with Fowler flaps is shown in figure 1.

The plain wing was constructed to NACA 66(215)-116, a = 0.6 sections at the root and to NACA 66(215)-216, a = 0.6 sections at the tip. Ordinates for these airfoils are given in tables I and II. Straight-line fairings were used between equal-percentage-chord stations at the root and tip. The wing plan form consists of a square center section, outboard sections having a taper ratio of 2:1, and elliptical tips. The trailing edge is straight and the leading edge is swept back 12.5°. The wing has a geometric washout of 1.5° between the outboard end of the center section and the extreme tip; this angle corresponds to an aerodynamic washout of approximately 0.8°. The maximum ordinate of each section along the span lies in the same horizontal plane, so that a small amount of dihedral is present. The span, area, and aspect ratio are 12 feet, 20.57 square feet, and 7.0, respectively.

The chord of the Fowler flap is 30 percent of the corresponding wing chord. The flap was constructed to a Göttingen 532 airfoil section modified on the lower surface to fit the wing contour. The ordinates for this flap are given in table III. The lower surface of the wing near the trailing edge was cut to the shape of the flap to serve as a retracting well (figs. 2 and 3). The nose of the flap was set in the optimum position for maximum lift as determined in an earlier part of the main investigation. (See fig. 2.) Flap deflection is the angle between the wing chord line and a line through the flap trailing edge tangent to the lower surface. The designation $\delta_f = 0^\circ$ means that the Fowler flap is fully extended and parallel to the wing chord line. The partial-span and full-span flap arrangements extended over 53 percent and 90 percent of the total wing span, respectively.

The chord of the split flap is 20 percent of the local wing chord. These flaps were attached directly to the under surface of the wing with the Fowler flaps retracted. Flap deflection is the angle between the under surface of the wing and the flap.

The wing and Fowler flaps were constructed of laminated mahogany. Smooth surfaces were obtained by spraying the wing and flaps with lacquer and then rubbing in the chordwise direction with No. 500 carborundum paper.

Tests

The method of mounting the wing in the test section of the tunnel is shown in figure 4. Measurements of lift, drag, and pitching moment were made over a range of angle of attack from -4° to beyond the stall. Tests were made to determine the tare and interference effects of the model-supporting struts on the wing. The stall characteristics of the wing-flap combinations were determined from visual observations of the behavior of tufts attached to the upper surface of the wing and flap. No tufts were placed ahead of the 20-percent-chord station.

The aerodynamic characteristics of the wing were obtained for the most part at a Reynolds number of approximately 3.5×10^6 and a Mach number of 0.13. Maximum lift was measured at Reynolds numbers ranging from 2.0×10^6 to 4.4×10^6 for some configurations. For all tests, the air in the tunnel was compressed to an absolute pressure of approximately 35 pounds per square inch.

RESULTS AND DISCUSSION

The data presented herein have been corrected for effects of model-support tare and interference and for air-stream misalinement. Jet-boundary corrections have been applied to the drag coefficient and angle of attack.

The basic force-test data for the wing with Fowler flaps are given in figures 5 and 6. The data for the flaps-retracted condition are also given in figure 5. Data for the wing with split flaps are presented in figures 7 and 8. The effects of Reynolds number, flap deflection, and flap span on maximum lift are shown in figures 9, 10, and 11, respectively. The effects of Reynolds number on the lift and pitching-moment characteristics of the wing with flaps retracted are shown in figure 12. The stall progressions are presented in figure 13.

<u>Lift and pitching-moment characteristics</u>.- The effects of Reynolds number on maximum lift coefficient are appreciable as shown in figure 9. The increment of $C_{L_{max}}$ due to Fowler flaps generally increased with Reynolds number but the increment due to split flaps changed very little.

The variations of increment of maximum lift with flap deflection shown in figure 10 indicate that the optimum deflection for the full-span Fowler flap is between 30° and 35°. For split flaps it appears that little gain in maximum lift would be obtained for deflections greater than 60°.

The variation of $\Delta C_{L_{max}}$ with flap span is indicated in figure 11. The increment of maximum lift due to Fowler flaps was almost directly proportional to the flap span. For split flaps the increment in lift going from partial-span to full-span flaps was less than that which would be obtained with a linear increase in lift.

Thus far the effectiveness of the flaps has been considered for the wing with the pitching moments untrimmed. There are large changes in pitching moment due to flaps, particularly with the Fowler flaps. Trimming the pitching moment would appreciably reduce the maximum lift available. The reductions in maximum lift coefficient due to trimming the pitching moments can be seen in the following table, which presents untrimmed values of $C_{L_{max}}$ and values of $C_{L_{max}}$ for trim about the aerodynamic center of the wing with flaps retracted:

	Fowler flaps; $\delta_f = 30^\circ$		Split flaps; $\delta_f = 60^\circ$		Flaps retracted
	Full span	Partial span	Full span	Partial span	
Untrimmed	3.27	2.49	2.43	2.07	1.28
Trimmed[1]	3.01	2.32	2.32	2.01	1.28

[1]Values based upon tail length of $2.75\bar{c}$; aerodynamic center located $0.145\bar{c}$ behind quarter-chord point of root section.

The values of maximum lift coefficient for the wing with flaps are large but it should be remembered that these values are for a wing alone with smooth surfaces. The addition of a fuselage and surface roughness would be expected to reduce the maximum lift available and these additions would also be expected to have a greater effect on the wing with Fowler flaps than with split flaps. The maximum lift coefficients for the low-drag wing with split flaps are approximately 5 percent lower than those obtained on comparable wings with conventional airfoil sections. (See references 2 and 3.)

Attention is called to the peculiar changes in slope of the lift and pitching-moment curves for the flaps-retracted condition at low lift coefficients. (See fig. 5.) It is significant that the portion of the curve with increased slope is in the region in which lowest profile drag is obtained. Outside this region a reduction in the slope of the lift curve occurs. As shown in figure 12, the lift and pitching-moment curves tend to straighten out with increasing Reynolds number.

Stalling characteristics.- Diagrams that show the progression of flow separation are presented in figure 13. For all configurations, the wing stalled suddenly, and in most cases completely, for a small increase in angle of attack beyond maximum lift. With flaps retracted or with partial-span split flaps there was some indication of the approaching wing stall; with Fowler flaps, however, there was no such indication.

With flaps retracted, trailing-edge separation began along the entire span at moderate lifts and spread forward to the 70-percent chord line at maximum lift. With partial-span split flaps, the complete stall was preceded by intermittent separation on the center half of the wing. The flow over the wing outer panels near the trailing edge was very rough for most angles of attack.

CONCLUSIONS

Tests in the Langley 19-foot pressure tunnel of an NACA 66-series 16-percent-thick low-drag tapered wing of 12-foot span with 0.30-chord Fowler and 0.20-chord split flaps led to the following conclusions:

1. The maximum lift coefficients obtained with full-span and partial-span Fowler flaps were 3.27 and 2.49 at a Reynolds number of 3.5×10^6. For the same conditions, the maximum lift coefficients obtained with split flaps were 2.43 and 2.07. The values of maximum lift coefficient for the wing with split flaps were somewhat lower (approximately 5 percent) than the values obtained for comparable wings with conventional airfoil sections. Trimming the large pitching moments due to flaps would appreciably reduce the maximum lift available, particularly for the Fowler flaps.

2. For all configurations investigated, the wing stalled suddenly, and in most cases completely, for a very small increase in angle of attack beyond maximum lift. With flaps retracted or with partial-span split flaps, there was some indication of the approaching wing stall; but with partial-span or full-span Fowler flaps there was no such indication.

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REFERENCES

1. Muse, Thomas C., and Neely, Robert H.: Wind-Tunnel Investigation of an NACA Low-Drag Tapered Wing with Straight Trailing Edge and Simple Split Flaps. NACA ACR, Dec. 1941.

2. Neely, Robert H.: Wind-Tunnel Tests of Two Tapered Wings with Straight Trailing Edges and with Constant-Chord Center Sections of Different Spans. NACA ARR, March 1943.

3. Neely, Robert H.: Wind-Tunnel Tests of an NACA 44R-Series Tapered Wing with a Straight Trailing Edge and a Constant-Chord Center Section. NACA RB No. 3L13, 1943.

TABLE I

ORDINATES FOR NACA 66(215)-116, a = 0.6 AIRFOIL SECTION

[Stations and ordinates in percent of wing chord]

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	--------	0	0
.435	1.214	.565	-1.150
.678	1.462	.822	-1.370
1.170	1.823	1.330	-1.683
2.408	2.498	2.592	-2.254
4.897	3.498	5.103	-3.082
7.392	4.286	7.608	-3.726
9.890	4.969	10.110	-4.281
14.894	6.054	15.106	-5.154
19.903	6.895	20.097	-5.827
24.916	7.554	25.084	-6.346
29.931	8.052	30.069	-6.738
34.949	8.401	35.051	-7.009
39.968	8.633	40.032	-7.185
44.989	8.734	45.011	-7.260
50.011	8.694	49.989	-7.220
55.037	8.502	54.963	-7.058
60.070	8.113	59.930	-6.737
65.096	7.459	64.904	-6.203
70.099	6.519	69.901	-5.419
75.091	5.429	74.909	-4.503
80.074	4.218	79.926	-3.478
85.053	2.995	84.947	-2.451
90.030	1.763	89.970	-1.411
95.011	.679	94.989	-.515
100.00	.077	100.000	-.077

L.E. radius: 1.575

Slope of radius: 0.055

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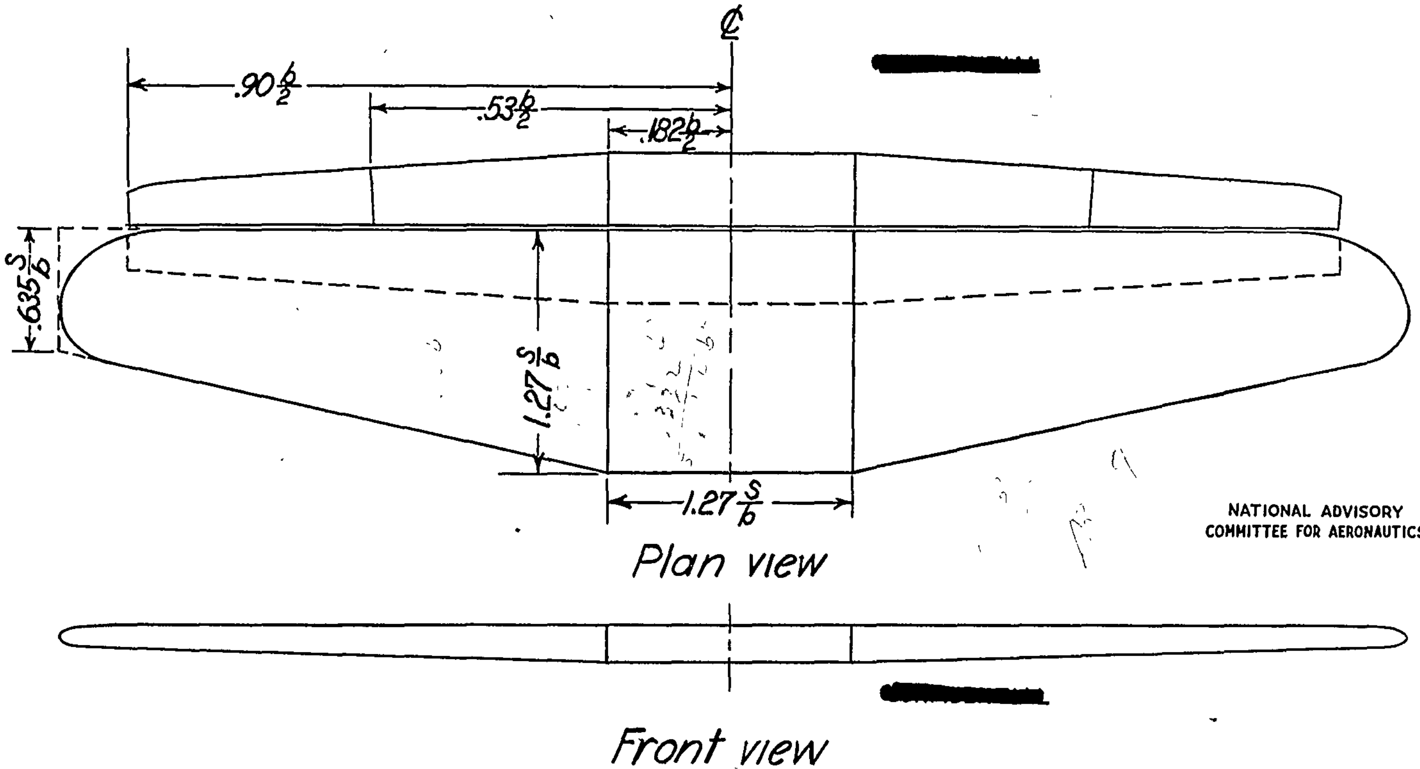

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Figure 1.- NACA 66-series low-drag tapered wing with 0.30c Fowler flaps extended.

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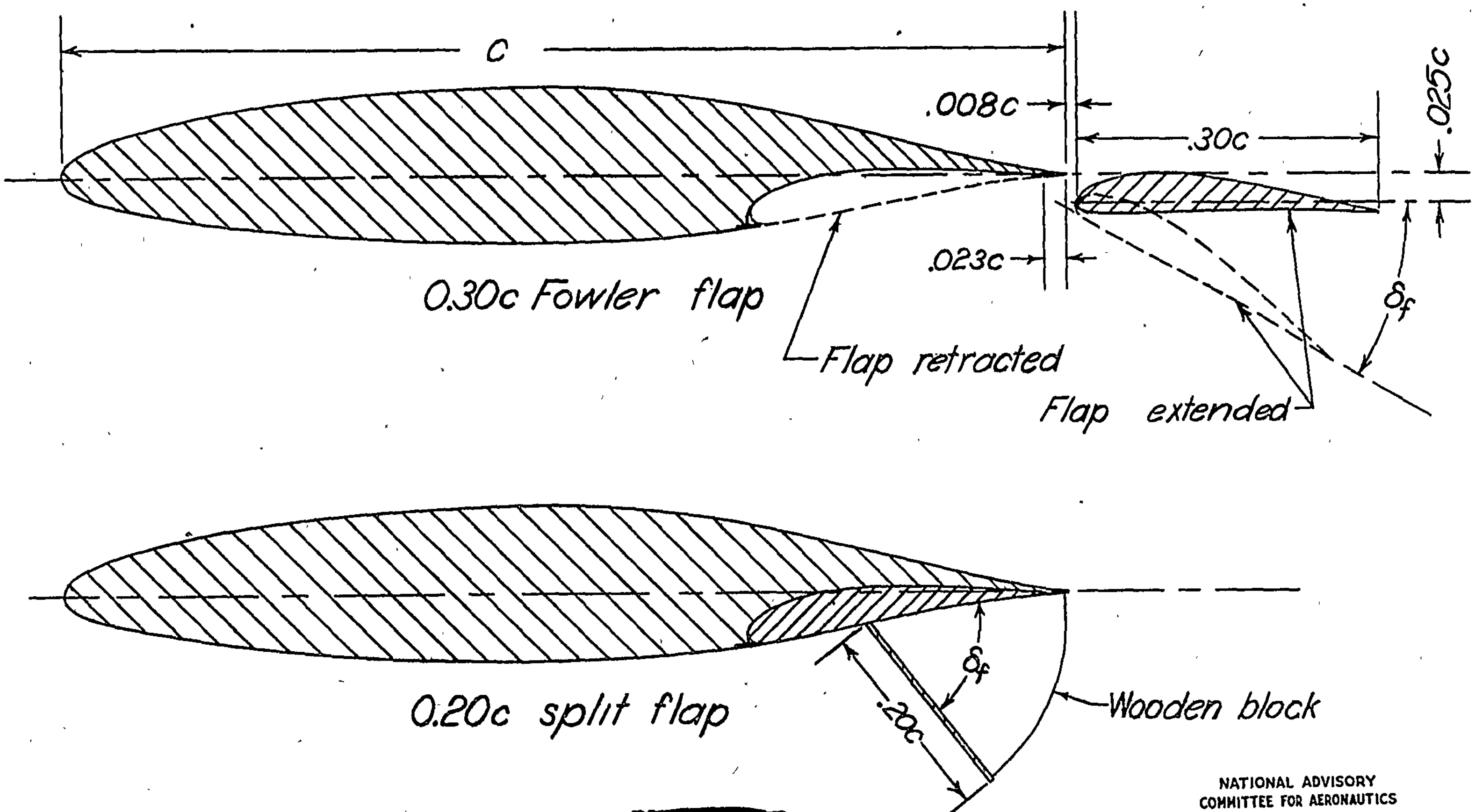

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Figure 2.- Flap details for NACA 66-series low-drag tapered wing.

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Figure 3.- Fowler flap in extended position.

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[redacted]

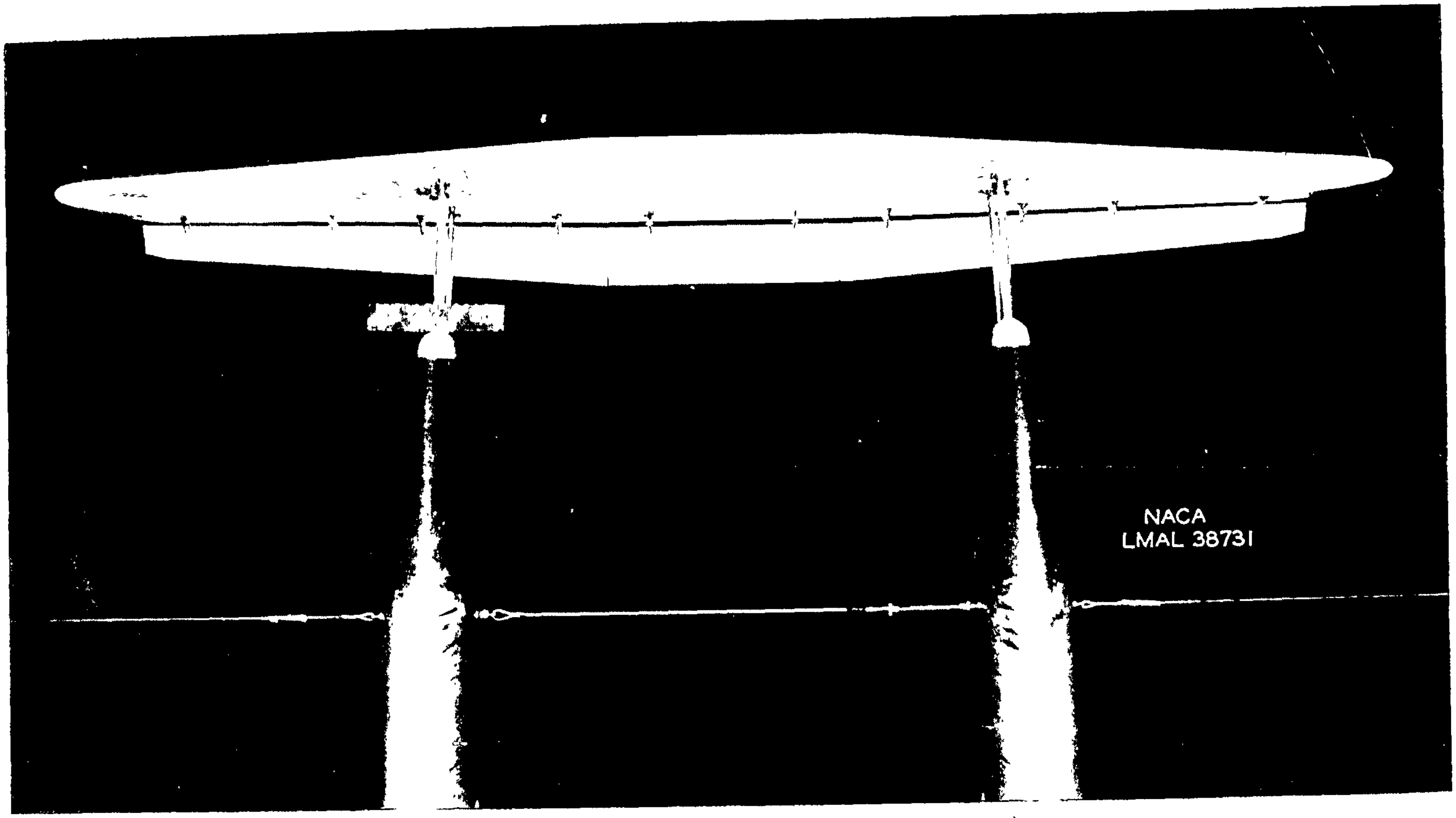

Figure 4.- Low-drag wing mounted in test section of Langley 19-foot pressure tunnel.

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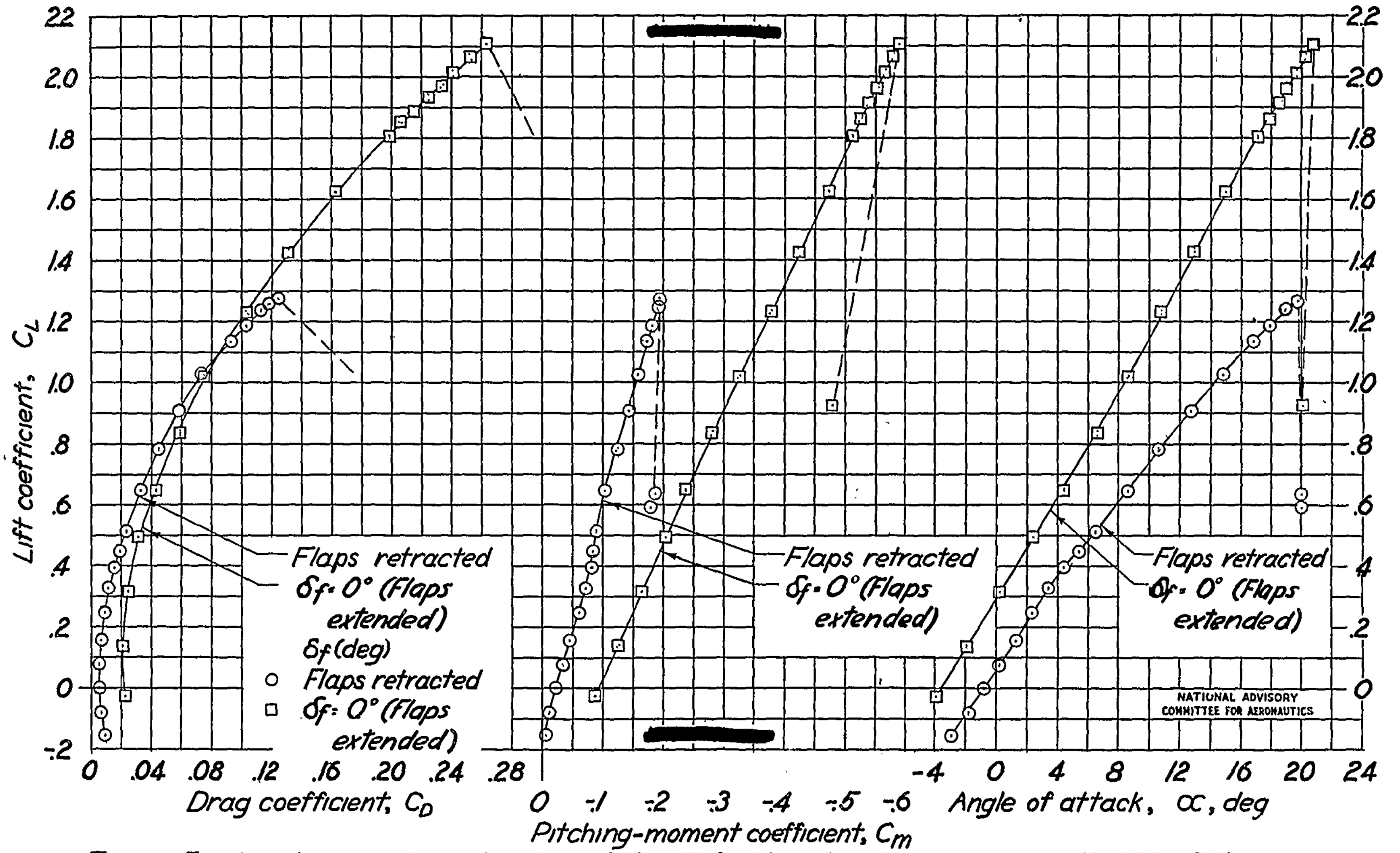

Figure 5.- Aerodynamic characteristics of the 12-foot low-drag tapered wing with 0.30c full-span Fowler flaps. $R \approx 3.4 \times 10^6$; $M = 0.13$.

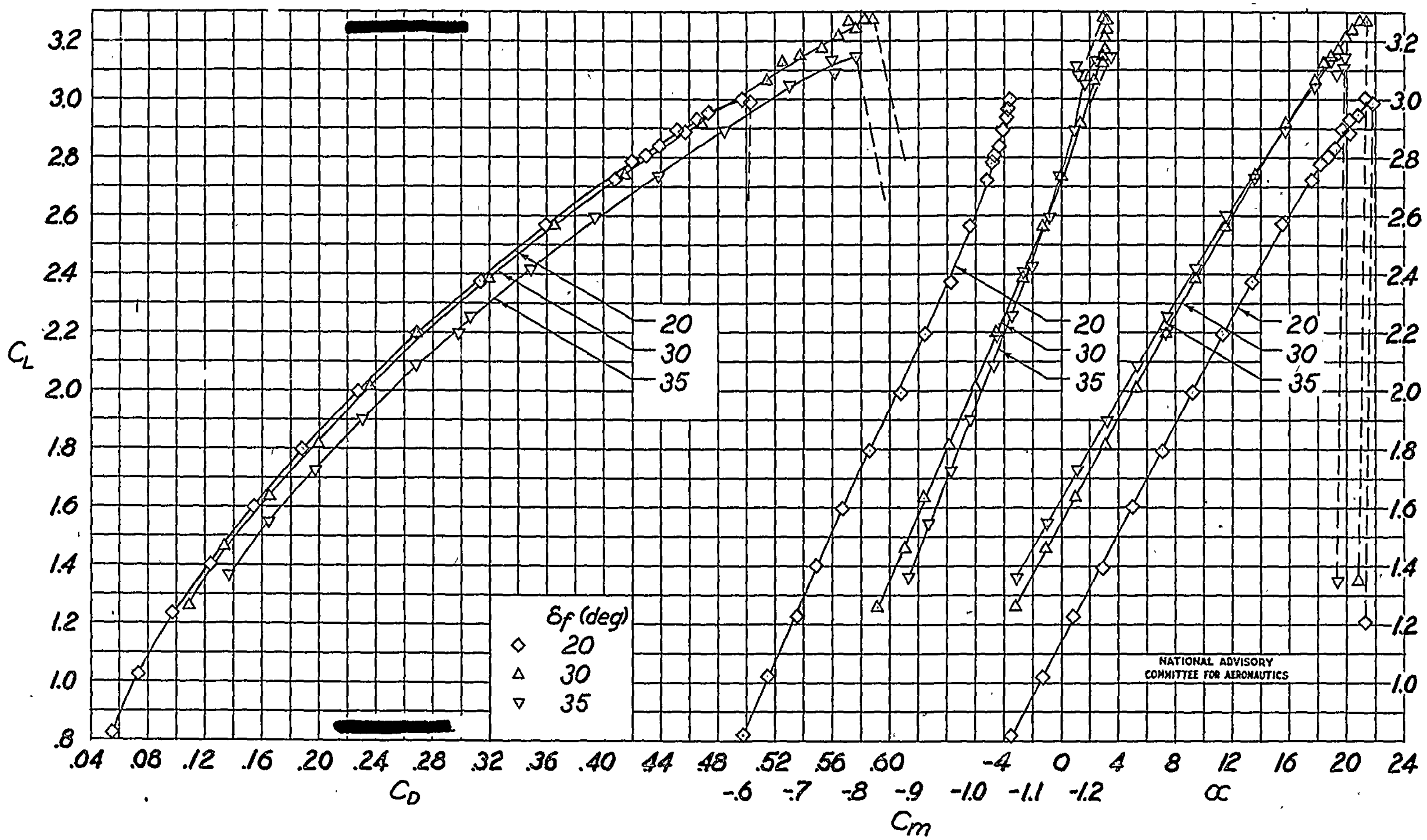

Figure 5 .-Concluded.

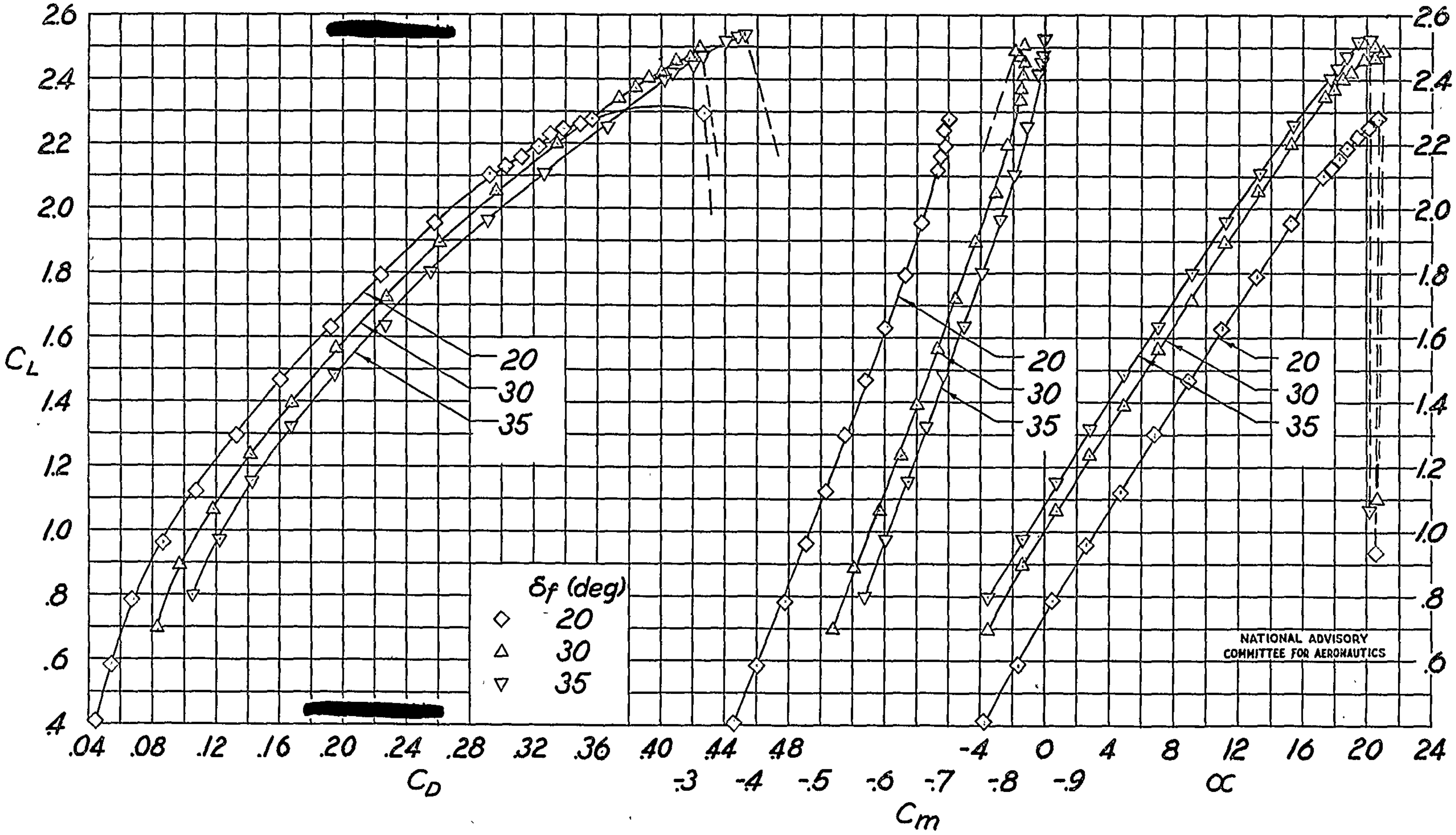

Figure 6 .–Aerodynamic characteristics of the 12-foot low-drag tapered wing with partial-span Fowler flaps. $R \approx 3.4 \times 10^6$; $M \approx 0.13$.

[redacted]

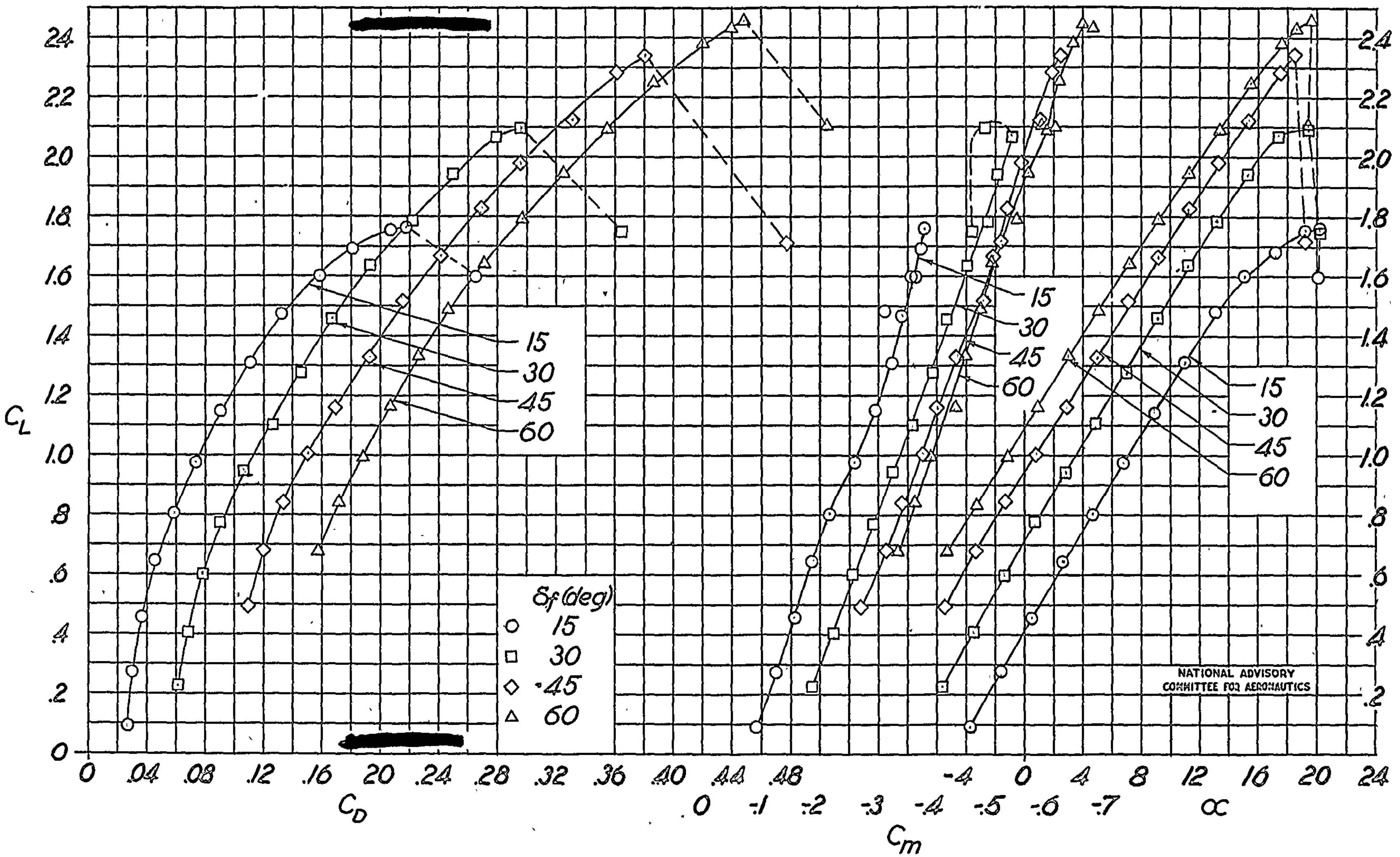

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Figure 7 .- Aerodynamic characteristics of the 12-foot low-drag tapered wing with 0.20c full-span split flaps. $R \approx 4.4 \times 10^6$; $M \approx 0.17$.

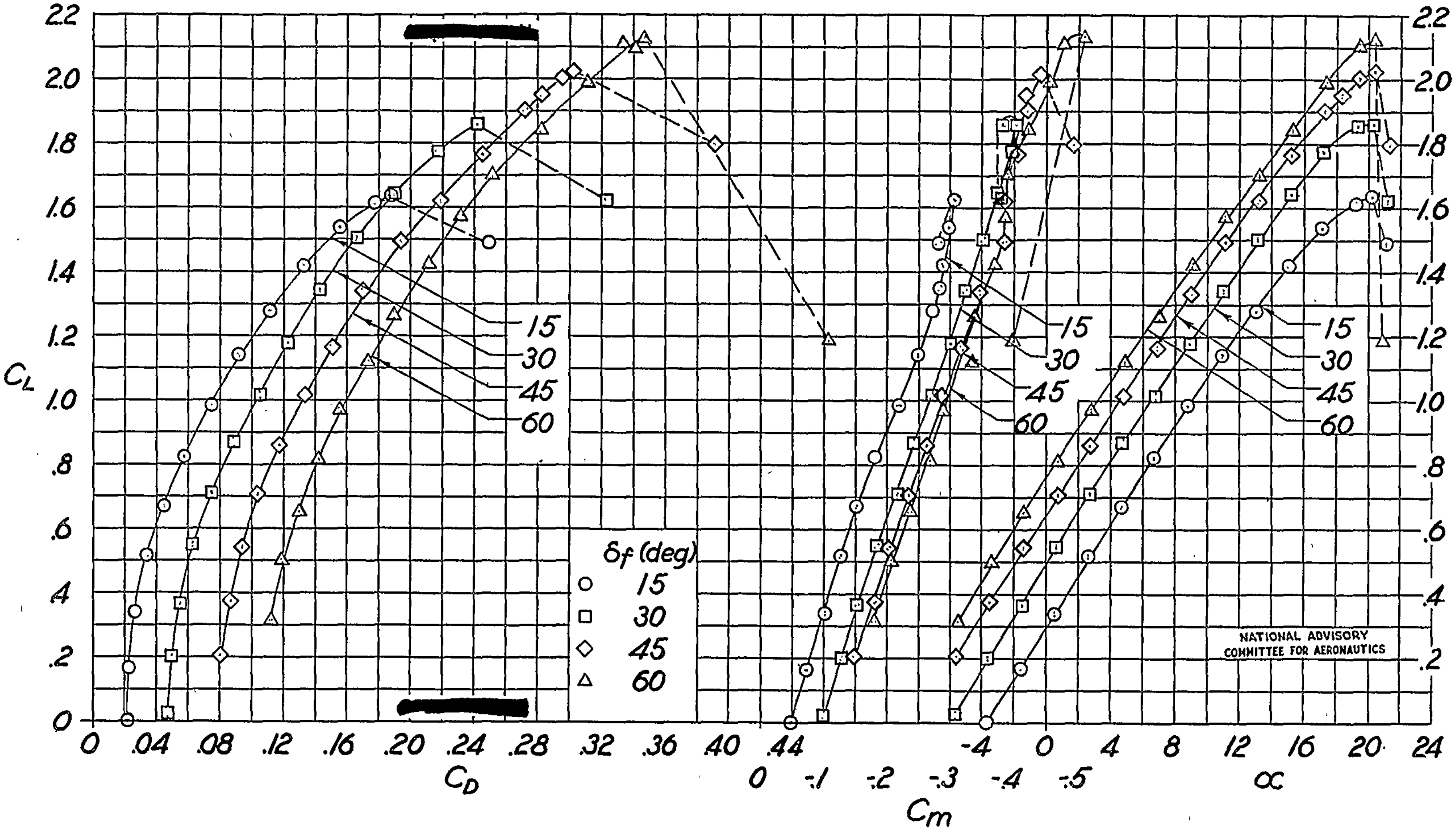
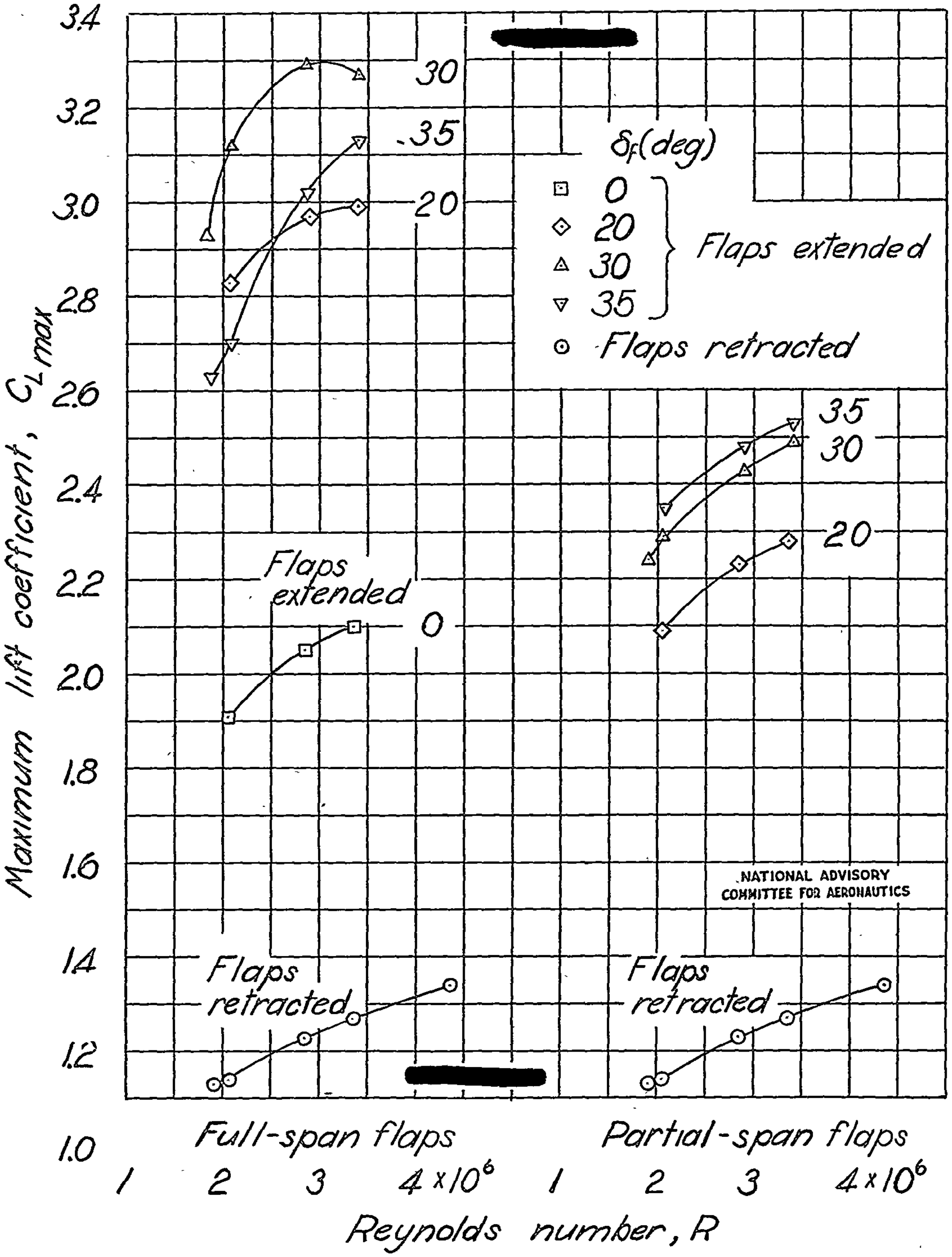


Figure 8.–Aerodynamic characteristics of the 12-foot low-drag tapered wing with 0.20c partial-span split flaps. $R \approx 4.4 \times 10^6$; $M \approx 0.17$.



(a) 0.30c Fowler flaps.

Figure 9.- Variation of maximum lift coefficient with Reynolds number for the 12-foot low-drag tapered wing.

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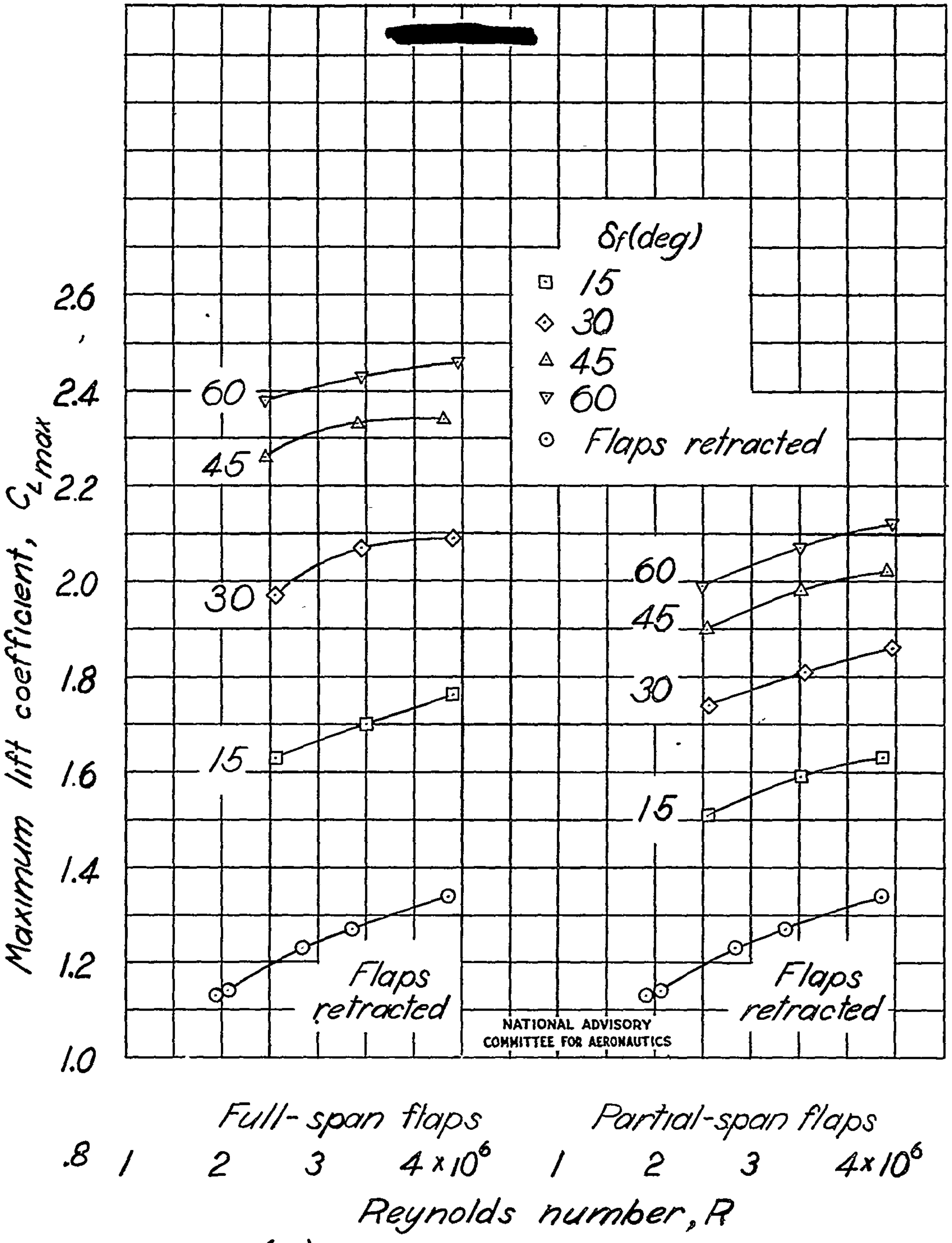
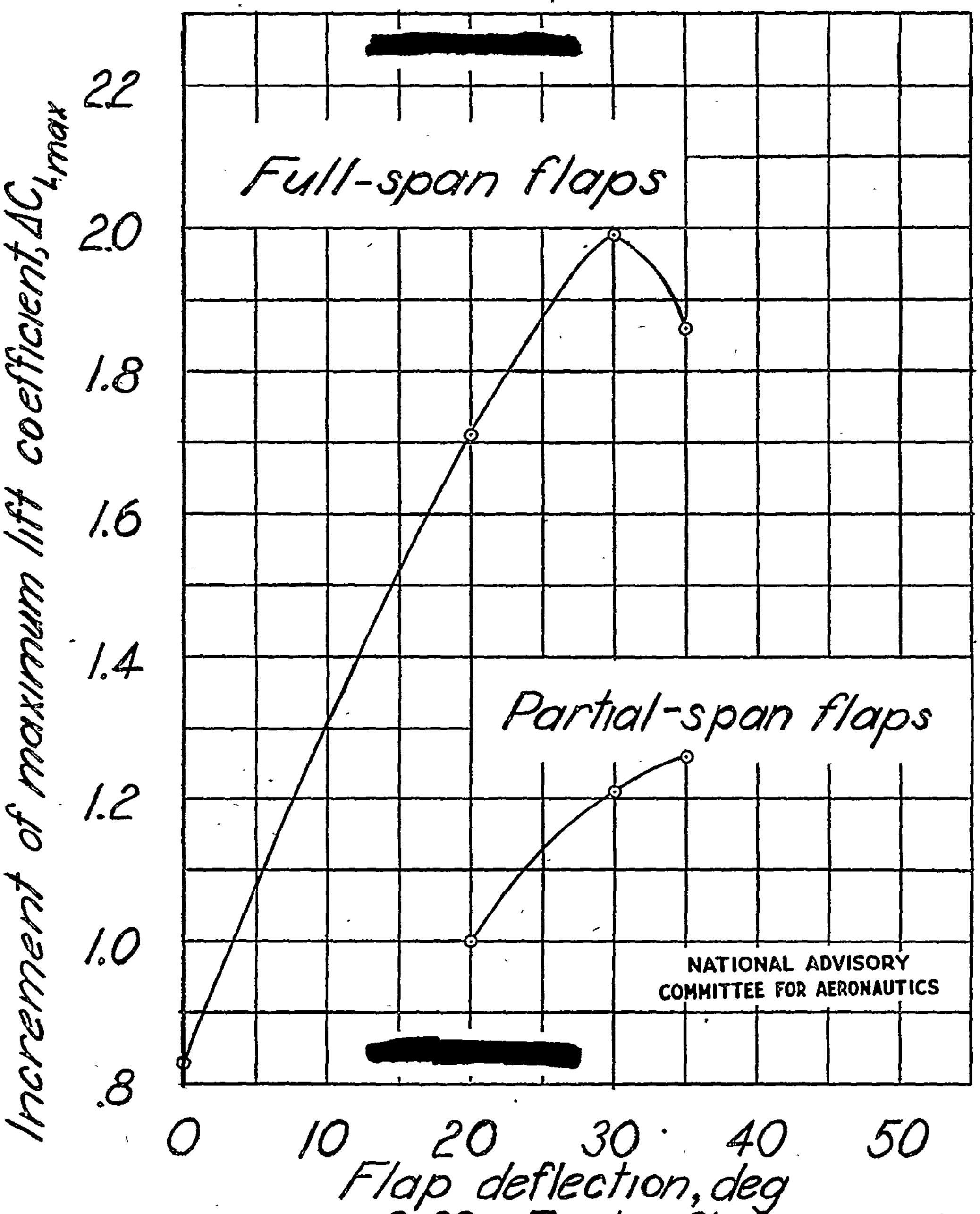


(b) 0.20c split flaps.

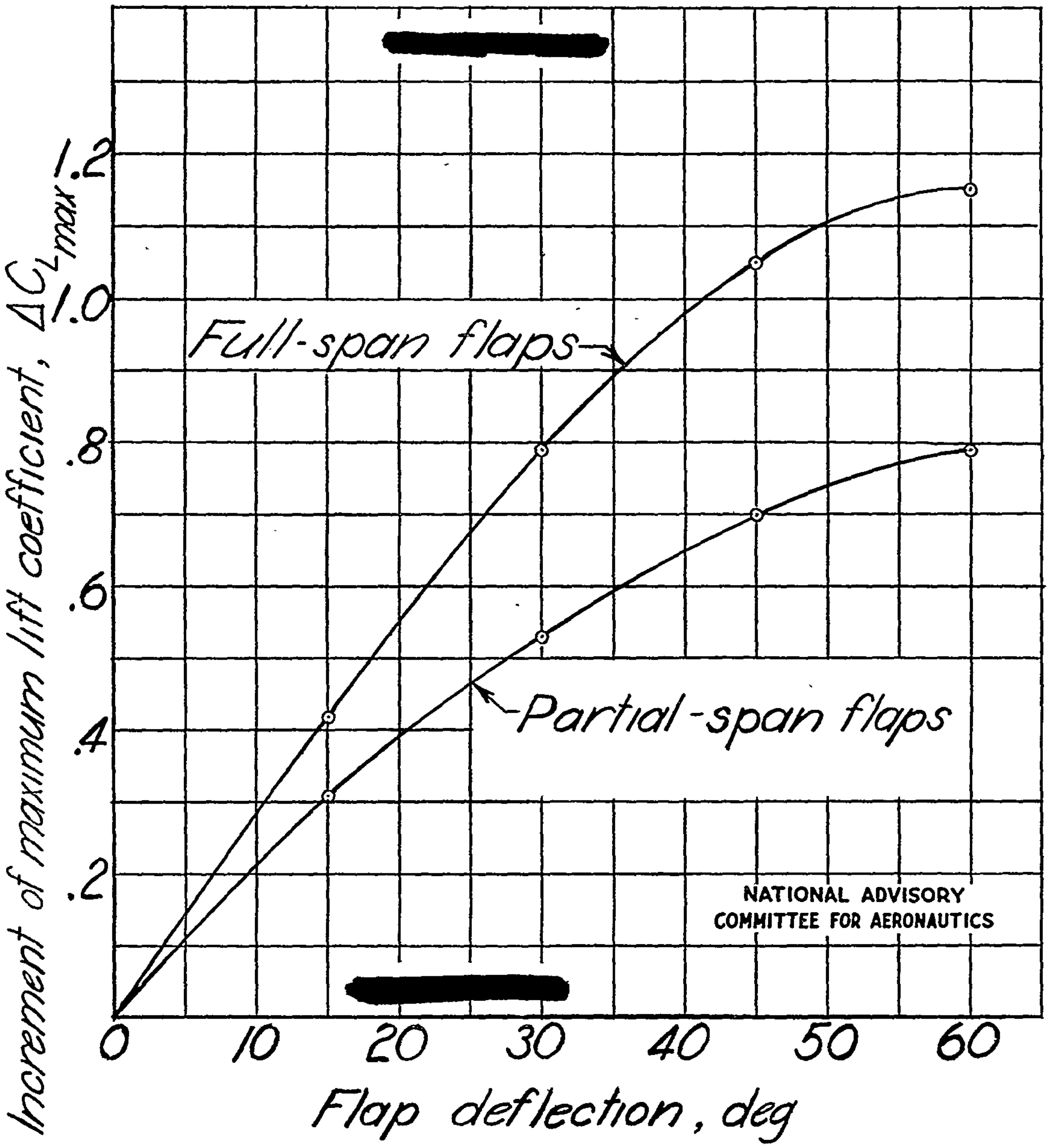
Figure 9.- Concluded.

[redacted]



(a) 0.30c Fowler flaps.

Figure 10.- Variation of increment of maximum lift coefficient with flap deflection for the 12-foot low-drag tapered wing; $R \approx 3,500,000$.



(b) 0.20c split flaps.

Figure 10.- Concluded.

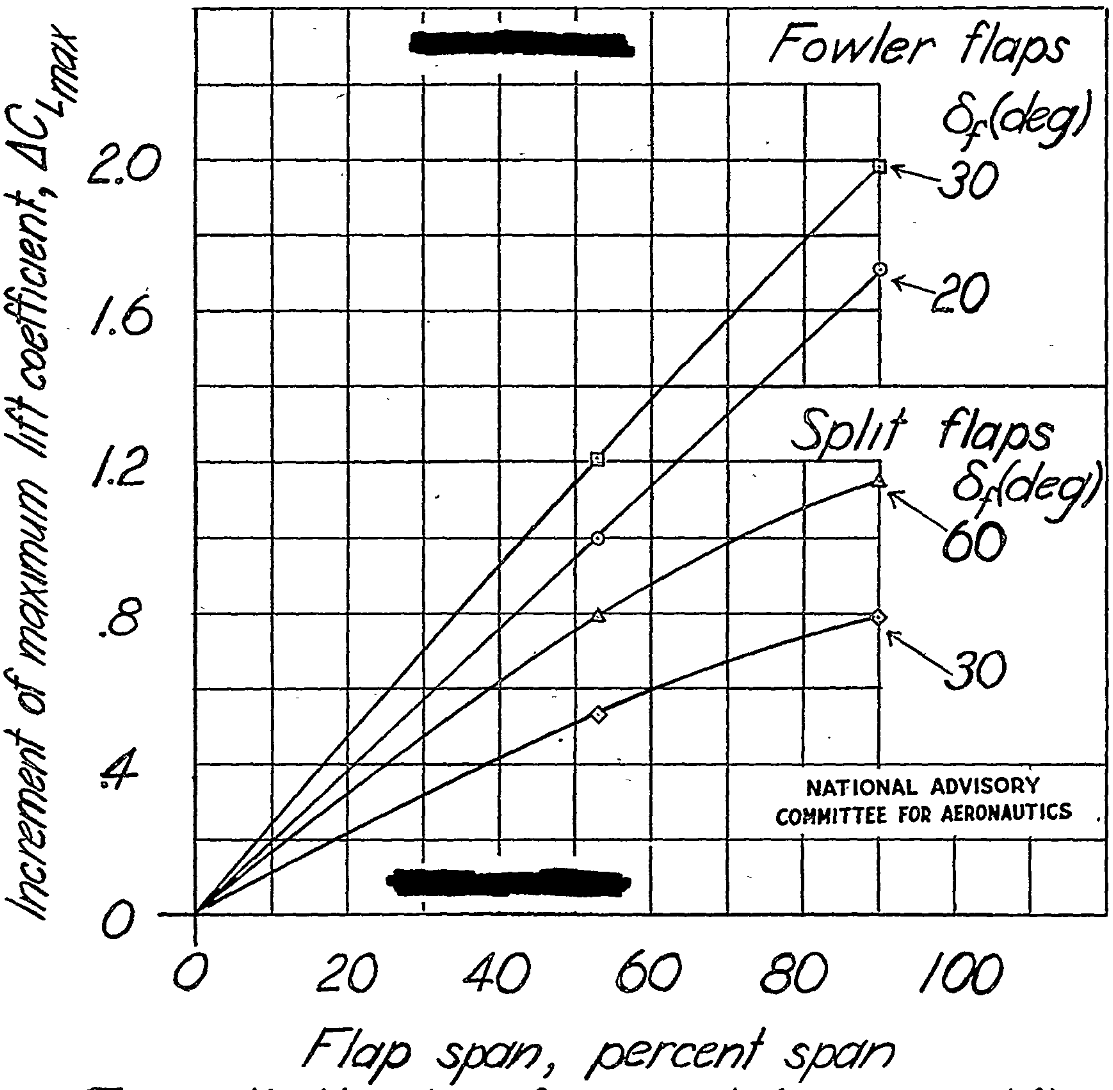


Figure 11. - Variation of increment of maximum lift coefficient with flap span for the 12-foot low-drag tapered wing; $R \approx 3,500,000$.

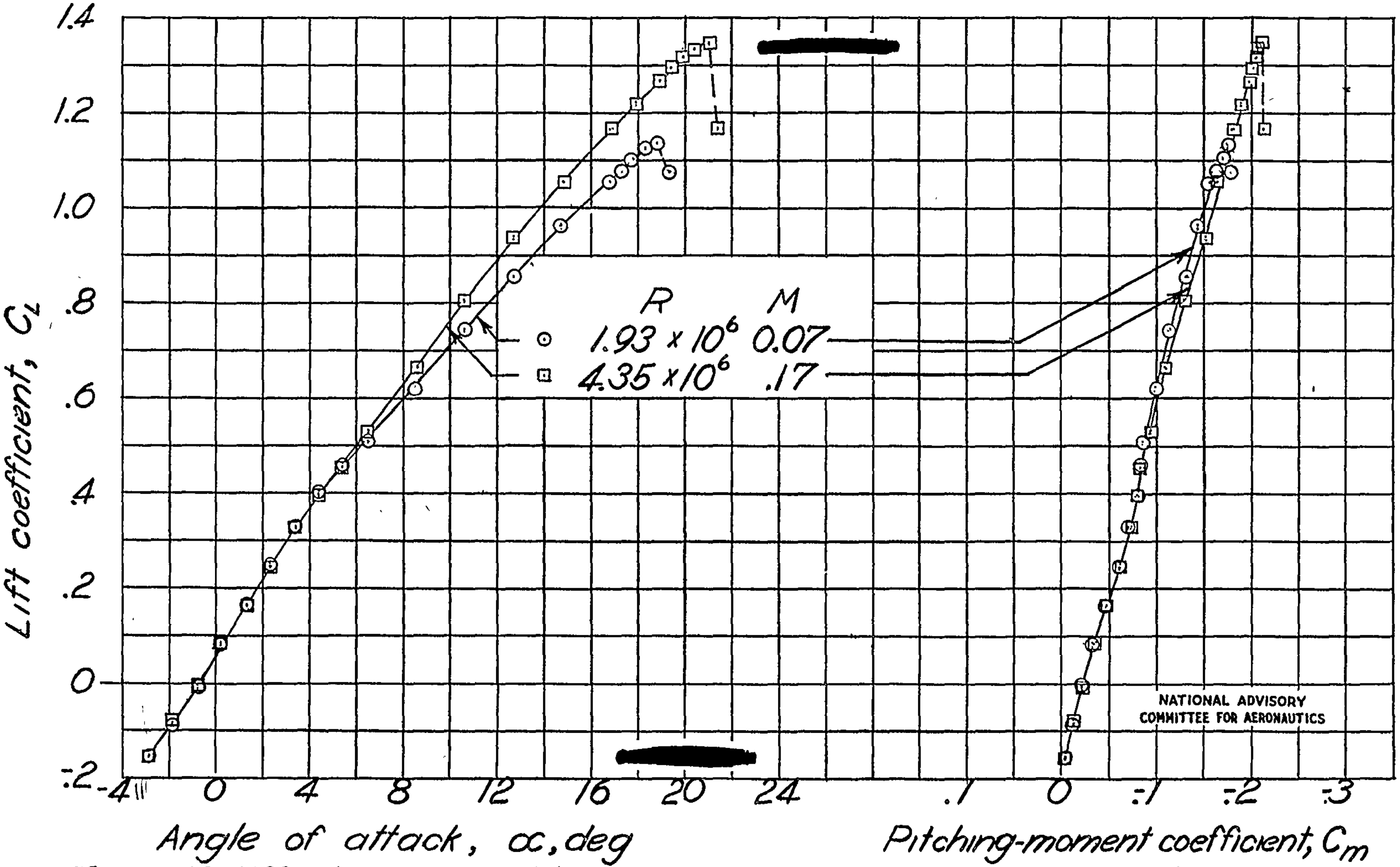


Figure 12.- Effect of Reynolds number on the lift and pitching-moment characteristics of the 12-foot low-drag tapered wing.

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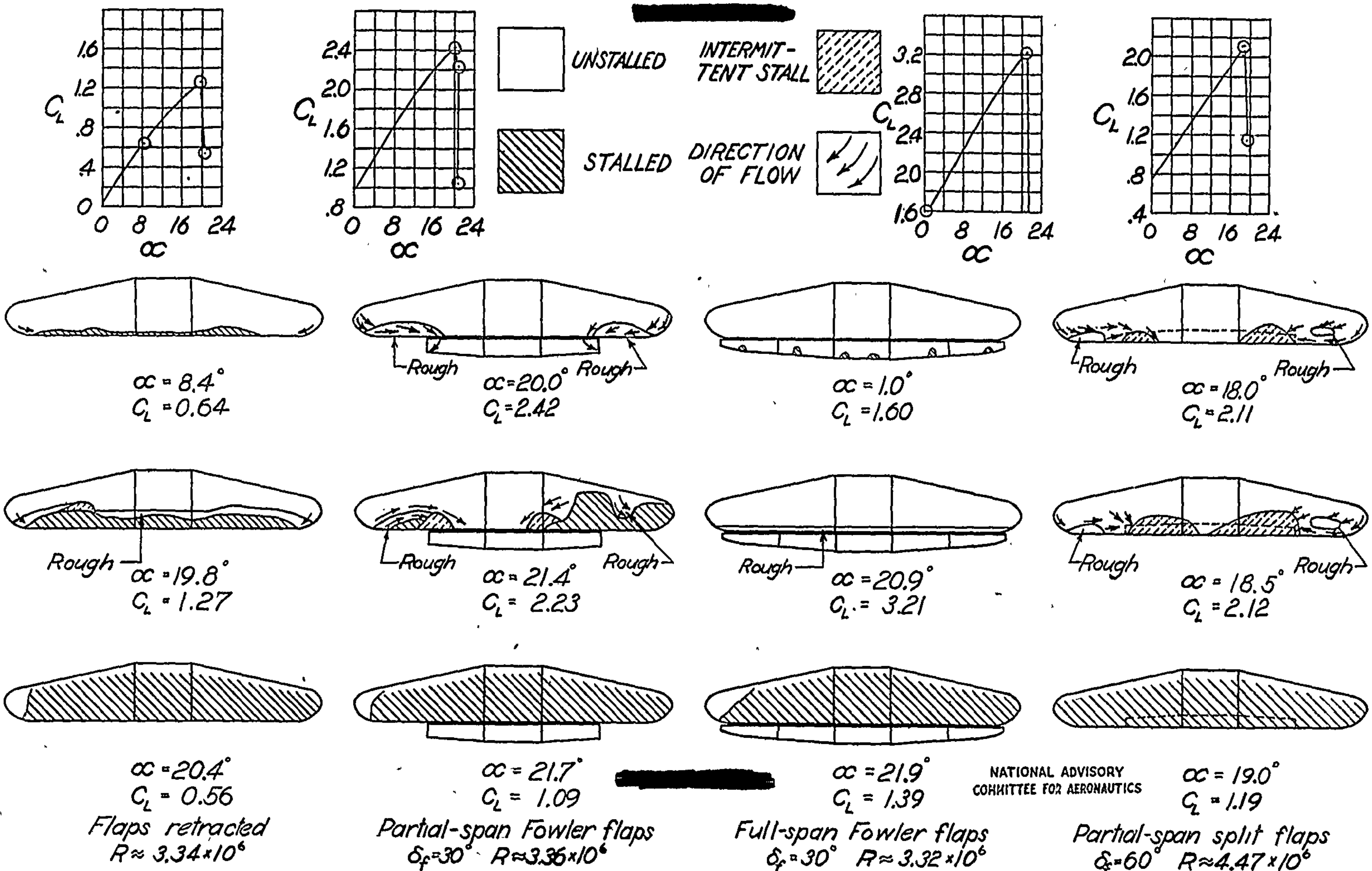

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Figure 13.-Stall diagrams of the 12-foot low-drag tapered wing.

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ATI- 7654

ORIG. AGENCY NUMBE

ACR-L5F28

REVISION

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AUTHOR(S)

DIVISION: Aerodynamics (2)
SECTION: Wings and Airfoils (6)
CROSS REFERENCES: Wings - Aerodynamics (99150); Flaps, Wing - Lift and drag characteristics (37550); NACA 66 (99150)(37550)

AMER. TITLE: Wind tunnel investigation of an NACA 66 series 16 percent thick low drag tapered wing with Fowler and split flaps

FORG'N. TITLE:

ORIGINATING AGENCY: National Advisory Committee for Aeronautics, Washington, D. C.

TRANSLATION:

COUNTRY	LANGUAGE	FORG'N.CLASS	U. S.CLASS.	DATE	PAGES	ILLUS.	FEATURES
U.S.	Eng.		Unclass.	Jan'46	21	20	photos, tables, diagrs, graphs

ABSTRACT

Aerodynamic characteristics of a wing with a straight trailing edge and a constant chord center section were investigated. Maximum lift coefficients obtained with fullspan and partial-span flaps were 3.27 and 2.49 at Reynolds Number 3.5×10^6. For the same conditions, the maximum lift coefficients obtained with split flaps were 2.43 and 2.07. For all configurations investigated the wing stalled suddenly in most cases, completely for a very small increase in angle of attack beyond maximum lift.

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